SUPERHEAVY PARTICLES IN FRIEDMANN COSMOLOGY AND THE DARK MATTER PROBLEM

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The model of creation of observable particles and particles of the dark matter, considered to be superheavy particles, due to particle creation by the gravitational field of the Friedmann model of the early Universe is given. Estimates on the parameters of the model leading to observable values of the baryon number of the Universe and the dark matter density are made.

It is well known[1,2] that creation of superheavy particles with the mass of the order of Grand Unification $M_X \approx 10^{14} - 10^{15}$ Gev with consequent decay on quarks and leptons with baryon charge and CP − nonconservation is sufficient for explanation of the observable baryonic charge of the Universe. Recently in papers[3,4] the possibility of explanation of experimental facts on observation of cosmic ray particles with the energy higher than the Greizen-Zatsepin-Kuzmin limit was discussed. The proposal is to consider the decay of superheavy particles with the mass of the order M_X. One can even consider the hypothesis that all dark matter consists of neutral X − particles with very low density. So it seems interesting to construct a model in which all matter as the observable one as the dark matter arise due to creation of X − particles by the gravitational field of the early Friedmann Universe. Gravitational field of the expanding Universe creates from vacuum particle and antiparticle pairs of X − bosons. In papers,[3,4] however, it was shown that if superheavy particles were stable, then the Universe will collapse very quickly. That is why as it was claimed in Refs. 1,2 these particles must decay with baryon charge and CP nonconservation. Then one has the problem how these particles can survive up to modern time and lead to observable cosmic rays effects? However, considering their decay in full analogy with theory of K^0 − mesons one must speak about decaying X_1^0 , X_2^0 − measons, which for simplicity are considered by us as conformal scalar particles, with different life times and per cent content in the initial mixture of X and $\bar{X}$ bosons.

So the problem is in the numerical estimate of the parameters of the effective Hamiltonian leading to the observable data. Short living X^0 − bosons decay on quarks and leptons in time close to singularity, long living X^0 − bosons exist today as the dark matter. Here we shall give this estimate. We shall not suppose any explicit realization (for example $SU(5)$ etc) of the Grand Unification, because any such realization with baryon charge and CP nonconservation must lead to our effective

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Hamiltonian. We also don't discuss the important problem of spontaneous breaking of the Grand Unification symmetry, surely influencing the difference of life times of particles of our model. We also neglect the effect of CPT – breaking in the expanding Universe, which can be important in the era of particle creation.[5]

At first let us remind some important results on creation of X – particle pairs in the early Friedmann Universe. Pairs of conformal scalar massive X – particles are created by the external gravitational field, the source of which is radiation with nonzero entropy and $p = \varepsilon/3$ equation of state. We don't discuss here the origin of this entropy (inflation or some other model) as well as creation of pairs from radiation. Particles are created by gravitation at the Compton time $t \sim M^{-1}$ and for $t \gg M^{-1}$ one has nonrelativistic gas of created particles with the energy density calculated for the radiation dominated Friedmann model[1] $a(t) = a_0\, t^{1/2}$:

$$\varepsilon^{(0)} = 2b^{(0)}\, M(M/t)^{3/2}\,, \tag{1}$$

where $b^{(0)} = 5.3 \cdot 10^{-4}$. Total number of created particles in the Lagrange volume is

$$N = n^{(0)}(t)\, a^3(t) = b^{(0)}\, M^{3/2}\, a_0^3\ . \tag{2}$$

In spite of the cosmological order of the number of created X – particles ($N \sim 10^{80}$ for $M_X \sim 10^{15}$ Gev, see Ref. 1.) their back reaction on the background metric is small in the sense that the background metric cannot arise due to these particles:[1]

$$\frac{\varepsilon_{part}}{\varepsilon_{bground}} \sim \frac{G}{t^2} = \left[\frac{1/t}{M_{Pl}}\right]^2 \ll 1\,, \quad \text{for} \quad t_{Pl} \ll t \ll \frac{1}{M}\,. \tag{3}$$

However for $t \gg M^{-1}$ there is an era of going from the radiation dominated model to the dust model of superheavy particles for $\varepsilon_{bground} \;\approx\; \varepsilon^{(0)}$,

$$t_X \approx \left(\frac{3}{64\pi\, b^{(0)}}\right)^2 \left(\frac{M_{Pl}}{M_X}\right)^4 \frac{1}{M_X}\,. \tag{4}$$

If $M_X \sim 10^{14}$ Gev, $t_X \sim 10^{-15}$ sec, if $M_X \sim 10^{13}$ Gev – $t_X \sim 10^{-10}$ sec. So the life time of short living X – mesons must be smaller then t_X. It is evident that if all created X – particles were stable, than the closed Friedmann model could quickly collapse, while all other models are strongly different from the observable Universe. Let us define d – the permitted part of long living X – mesons — from the condition: on the moment of recombination t_{rec} in the observable Universe one has

$$d\, \varepsilon_X(t_{rec}) = \varepsilon_{crit}(t_{rec})\,,$$

$$d = \frac{3}{64\pi\, b^{(0)}} \left(\frac{M_{Pl}}{M_X}\right)^2 \frac{1}{\sqrt{M_X\, t_{rec}}}\,. \tag{5}$$

For $M_X = 10^{13} - 10^{14}$ Gev one has $d \approx 10^{-12} - 10^{-14}$. Using the estimate for the velocity of change of the concentration of long living superheavy particles[6] $|\dot{n}_x| \sim 10^{-42}\,\text{cm}^{-3}\,\text{sec}^{-1}$, and taking the life time τ_X of long living particles as $2 \cdot 10^{22}$ sec we obtain concentration $n_X \approx 2 \cdot 10^{-20}\,\text{cm}^{-3}$ at the modern epoch, corresponding to the critical density for $M_X = 10^{14}$ Gev.

Now let us construct the toy model which can give: a) short living X – mesons decay in time $\tau_q < 10^{-15}$ sec, (more wishful is $\tau_q \sim 10^{-38} - 10^{-35}$ sec), long living mesons decay with $\tau_l > t_U \approx 10^{18}$ sec (t_U – age of the Universe). b) one has small $d \sim 10^{-14} - 10^{-12}$ part of long living X – mesons, forming the dark matter.

Baryon charge nonconservation with CP – nonconservation in full analogy with the K^0 – meson theory with nonconserved hypercharge and CP – nonconservation leads to the effective Hamiltonian of the decaying $X, \bar{X}$ – mesons with nonhermitean matrix.

The matrix of the effective Hamiltonian is in standard notations[7]

$$H = \begin{pmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{pmatrix}. \tag{6}$$

Let $H_{11} = H_{22}$ (due to CPT-invariance). Denote $\varepsilon = (\sqrt{H_{12}} - \sqrt{H_{21}}\,)\,/\,(\sqrt{H_{12}} + \sqrt{H_{21}}\,)$. The eigenvalues $\lambda_{1,2}$ and eigenvectors $|\,\Psi_{1,2}>$ of matrix H are

$$\lambda_{1,2} = H_{11} \pm \frac{H_{12} + H_{21}}{2}\,\frac{1-\varepsilon^2}{1+\varepsilon^2}\,, \tag{7}$$

$$|\,\Psi_{1,2}> = \frac{1}{\sqrt{2\,(1+|\varepsilon|^2)}}\left[(1+\varepsilon)\,|\,1> \pm (1-\varepsilon)\,|\,2>\right]. \tag{8}$$

In particular

$$H = \begin{pmatrix} E - \frac{i}{4}\left(\tau_q^{-1} + \tau_l^{-1}\right) & \frac{1+\varepsilon}{1-\varepsilon}\left[A - \frac{i}{4}\left(\tau_q^{-1} - \tau_l^{-1}\right)\right] \\ \frac{1-\varepsilon}{1+\varepsilon}\left[A - \frac{i}{4}\left(\tau_q^{-1} - \tau_l^{-1}\right)\right] & E - \frac{i}{4}\left(\tau_q^{-1} + \tau_l^{-1}\right) \end{pmatrix}. \tag{9}$$

Then the state $|\,\Psi_1>$ describes short living particles with the life time τ_q and mass $E + A$. The state $|\,\Psi_2>$ is the state of long living particles with life time τ_l and mass $E - A$. Here A is the arbitrary parameter $-E < A < E$ and it can be zero, $E = M_X$.

If $d = 1 - |<\Psi_1\,|\,\Psi_2>|^2 = 1 - |2\,\mathrm{Re}\,\varepsilon/(1+|\varepsilon|^2)|^2$ is the relative part of long living particles and ε is real, then $\varepsilon = (1-\sqrt{d}\,)/\sqrt{1-d}$ ($\varepsilon \sim 1 - 10^{-7}$ for $M_X \sim 10^{14}$ Gev). So one has a typical example of "fine tuning" in order to obtain the desired result.

Taking $\tau_q = 10^{-35}$ sec and $\tau_l = 2 \cdot 10^{22}$ sec, one obtains that for the Hermitean part $(H + H^{+})/2$ of H nondiagonal CP-noninvariant term equal to $i\,(\tau_q^{-1} - \tau_l^{-1})\,\varepsilon/(1-\varepsilon^2)/2$ is of the order of Planckean mass 10^{19} Gev.

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